Measurement of F_2 at Medium Q^2 and the PDF Determination using H1 HERA I Data

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A new measurement of the inclusive DIS cross section $ep \to e'X$ using H1 data from the year 2000 is performed and combined with published results using 1996/97 data. The new data covers the region of $12\,\mathrm{GeV}^2 \leq Q^2 \leq 150\,\mathrm{GeV}^2$ at HERA with unprecedented accuracy. The structure Function F_2 is extracted and studied. A QCD analysis, H1PDF 2009, is performed including the new and published H1 inclusive measurements.

1 Introduction

The HERA collider facility in Hamburg, Germany, was a unique machine for lepton-proton scattering at highest energies. Here a new analysis of data taken with the H1 detector in the year 2000 is discussed [2], when protons with an energy of 920 GeV were collided with positrons with an energy of 27.6 GeV, corresponding to a centre of mass energy of $\sqrt{s} = 320$ GeV.

Deep Inelastic Scattering (DIS) of leptons off nucleons continues to be the tool for high precision measurements of the quark and gluon content of the nucleons in the form of so called parton distribution functions (PDFs). The evolution of PDFs is a sensitive test of our understanding of QCD dynamics, which is expressed in the form of evolution equations. Furthermore a precise knowledge of PDFs is vital for measurements at hadron colliders, such as the LHC.

The kinematics of the scattering are described in terms of the Lorentz invariant quantities: the Bjorken scaling variable x, the inelasticity y, and the virtuality Q^2. The neutral current (NC) inclusive cross section for the reaction $ep \to e'X$ at low $Q^2 \ll M_Z^2$ can be expressed in the form

$$\frac{\mathrm{d}^2\sigma^{NC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2 Y_+}{xQ^4}\left(F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)\right) \tag{1}$$

with $Y_+ = 1+(1-y)^2$ and the structure functions F_2 and F_L. At leading order, the structure function F_2 relates to the quark distribution functions simply as

$$F_2 = x\sum e_q^2(q(x) + \bar{q}(x))\,. \tag{2}$$

In higher orders the Bjorken scaling is violated and F_2 depends also on Q^2. The derivative $\partial F_2(x,Q^2)/\partial \ln Q^2$ is related to the gluon distribution $xg(x,Q^2)$ and the value of the strong coupling constant α_s.

The longitudinal structure function vanishes at leading order. Its contribution to the cross section is $\propto y^2$ and thus very small for the new analysis, which is restricted to $y < 0.6$. Analyses focusing on the high y domain and the F_L determination have been presented elsewhere [3].

2 New Cross Section Measurement

The new measurement of the DIS cross section is performed using data taken with the H1 apparatus in the year 2000. The integrated luminosity of the sample is $22\,\mathrm{pb}^{-1}$. For $12\,\mathrm{GeV}^2 \leq Q^2 \leq 150\,\mathrm{GeV}^2$ the scattered positron is detected in the backward region of H1. The SpaCal calorimeter and the planar drift chamber BDC are used to identify the scattered positron and to measure its energy E'_e. The Central Tracker is used to reconstruct the event vertex and, in connection with the backward detectors, the positron scattering angle θ_e. The hadronic final state (HFS) is reconstructed from a combination of tracks and calorimeter measurements, where the transverse momentum, P_T^h, and the total difference between energy and longitudinal momentum $E - p_z = \sum_i (E_i - P_{z,i}) + E'_e(1 - \cos\theta_e)$ are especially useful quantities. Control distributions of these four basic variables characterising the scattered positron and the HFS are shown in figure 1, where an excellent agreement between data and simulation is observed.

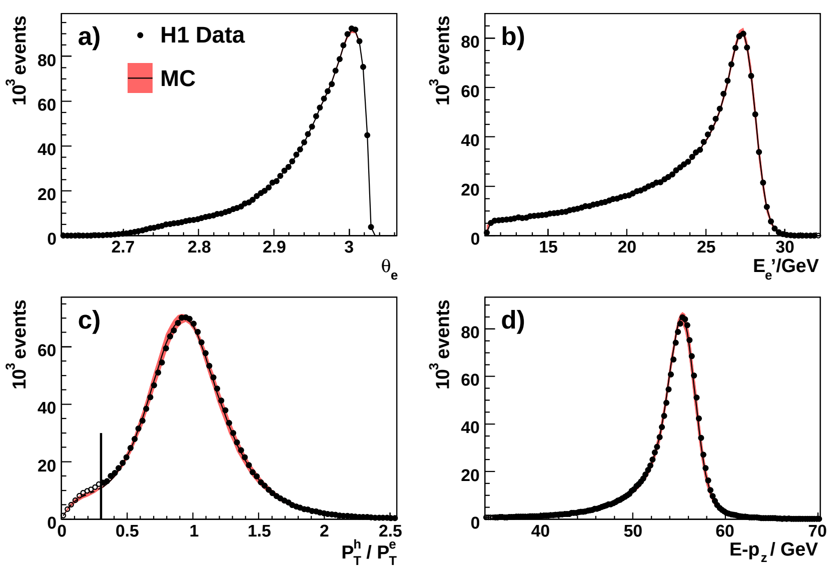

Figure 1: Control distributions of the polar angle a) and the energy b) of the scattered positron, the transverse momentum ratio $p_{t,HFS}/p_{t,e}$ c) and $E - p_z$ d).

The good control of the relevant detector quantities expresses itself in small systematic uncertainties. For example, the positron energy scale is controlled to better than $0.2-1\%$ and the HFS energy to $\sim 2\%$. The relevant detector and reconstruction efficiencies are known to typically better than $0.3-0.5\%$. The event kinematics is reconstructed using the Electron method at larger $y \gtrsim 0.1$ and the Σ method at lower y [4].

3 Combination with Published Results and Results on F_2

The new measurement [2] covers a similar kinematic domain as the previously best H1 measurement using data from 1996/97 with a proton beam energy of 820 GeV [5]. The total

uncertainties are improved by up to a factor ~ 2 for newer data. The comparison with the older data revealed a small Q^2 dependent bias in the published results of $\sim 0 - 2.5\%$, which is corrected.

The two data sets are averaged using the same technique as introduced for the combination of the lower $Q^2 \leq 12\,\mathrm{GeV}^2$ data sets of H1 [4] with a proper treatment of bin-to-bin correlated uncertainties. The 1996/97 cross sections are adjusted for the small difference in the centre of mass energies for lower $y < 0.35$. Measurements at higher y are kept separate. The correlated systematic uncertainty sources for measurements within a data set are treated as uncorrelated between the data sets, only small shifts of the central values are required. The consistency between the data sets is good with a $\chi^2_{\mathrm{tot}}/n_{\mathrm{dof}} = 51.6/61$.

The combined data represent the most precise inclusive measurement in the covered kinematic domain to date. The structure function F_2 is extracted for $y < 0.6$ by applying a small correction for the F_L influence, which is taken from the NLO QCD fit H1PDF 2009, see section 4. Figure 2 shows the evolution of H1 measurement uncertainties on the structure function F_2 at $Q^2 = 15\,\mathrm{GeV}^2$. The typical total uncertainties have now reached a level of $1.3 - 2\%$.

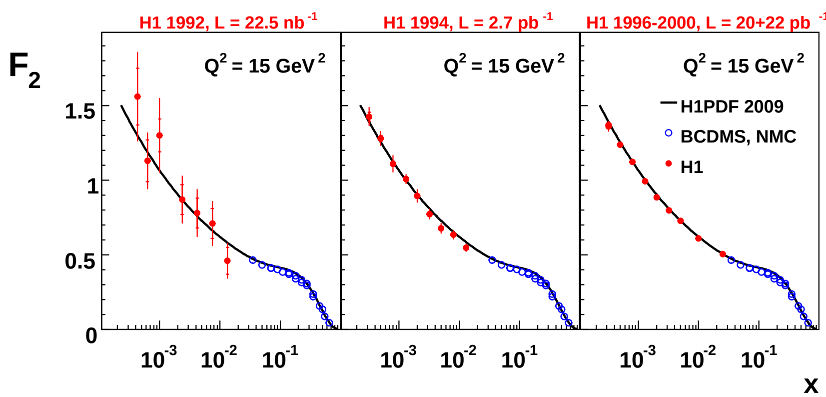

Figure 2: Measurements of the structure function F_2 at $Q^2 = 15\,\mathrm{GeV}^2$ by the H1 collaboration at low x complemented by fixed target data at higher x. The precision is seen to increase impressively over time, with the latest result reaching typically $1.3 - 2\%$ total uncertainty.

The steep rise of F_2 towards low x is well described by QCD fit. At low $x < 0.01$ the rise of F_2 towards low x essentially compatible with a power law $F_2 \propto x^{-\lambda}$, but a small deviation from this behaviour at lowest x is also not excluded. Figure 3 shows a compilation of H1 data on F_2 at fixed x, including results from lower [4] and higher Q^2 [6]. Strong scaling violations are observed at low x, while at high $x \sim 0.1$ F_2 is nearly independent of Q^2. The effect of the QCD dynamics is well described by the fit down to very low $Q^2 \sim 1.5\,\mathrm{GeV}^2$.

4 The H1PDF 2009 QCD Fit

Using only inclusive cross section data by H1, a new QCD fit based on DGLAP evolution equations at NLO was performed. Compared to the previously published fit H1PDF 2000 [6], the data used at lower $Q^2 \leq 150\,\mathrm{GeV}^2$ includes two new analyses [2, 4] and is more precise.

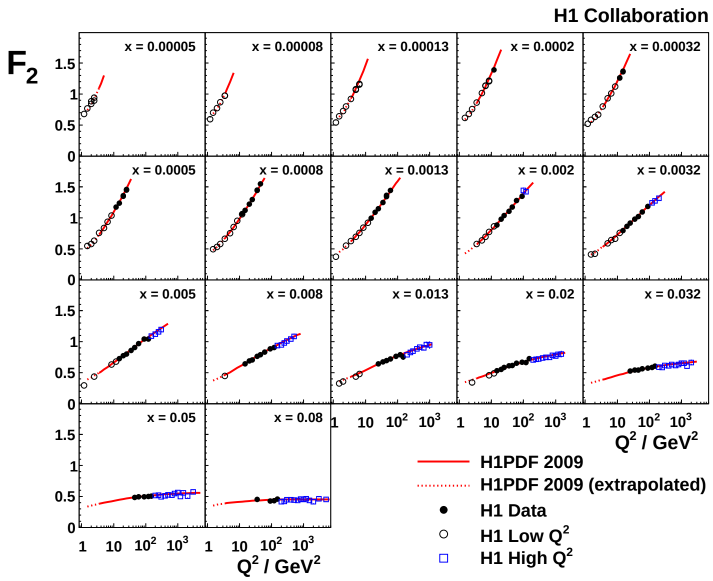

Figure 3: Measurements of the structure function F_2 by the H1 collaboration at constant x as a function of Q^2.

Also the theoretical treatment of heavy quark threshold effects was improved by employing a GM-VFNS scheme [7].

The chosen PDF set $xu_v, xd_v, xg, x\bar{U} = x(\bar{u} + \bar{c}), x\bar{D} = x(\bar{d} + \bar{s} + \bar{b})$ is parameterised at low $Q_0^2 = 1.9\,\mathrm{GeV}^2$ as $xP = Ax^B(1-x)^C(1 + Dx + Ex^2 + \ldots)$. Six parameters are fixed by model assumptions and momentum and quark counting rules. The remaining nine A, B, C parameters form the basic parameterisation. Further $D, E, \ldots$ parameters are considered in an iterative χ^2 optimisation procedure. Additional conditions apply for parameters, which are to be used for the fit eventually. Both structure functions F_2 and F_L should be positive. Furthermore, if fits with negative PDFs or very low valence quark compared to the sea quark distributions at high x are found, those are not considered for the central result, but used to give an estimate of the parameterisation uncertainty. Eventually only one parameter, D_g, is added to the basic parametrisation. This fit has a good $\chi^2_{\mathrm{tot}}/\,n_{\mathrm{dof}} = 587/644$ with no significant tension in the systematic uncertainties.

The value of the strong coupling constant is fixed to $\alpha_s = 0.1176$. The further theory model parameters are chosen as $Q_0^2 = 1.9\,\mathrm{GeV}^2$, $m_c = 1.4\,\mathrm{GeV}$, $m_b = 4.75\,\mathrm{GeV}$ and the strange sea fraction $f_s = x\bar{s}/x\bar{D} = 0.31$, which are varied in reasonable limits [2]. The largest model uncertainty occurs on the gluon density at low x, which is caused by the Q_0^2 variation.

The PDFs for the valence quarks, the gluon, and the total sea density $xS = x(\bar{U} + \bar{D})$ are shown with all uncertainties in figure 4 at a scale of $Q^2 = 10\,\mathrm{GeV}^2$. The experimental errors are in general small compared to the model and parametrisation errors. The gluon clearly dominates low x domain even at this relatively low scale. Compared to H1PDF 2000 the low x uncertainties are reduced, while the uncertainties at high x larger and more realistic.

Comparing to the latest combined H1 and ZEUS fit, HERAPDF 0.2 [8], similar features are observed. The combined fit profits from the data combination, which is seen to constrain the PDFs further especially at higher x.

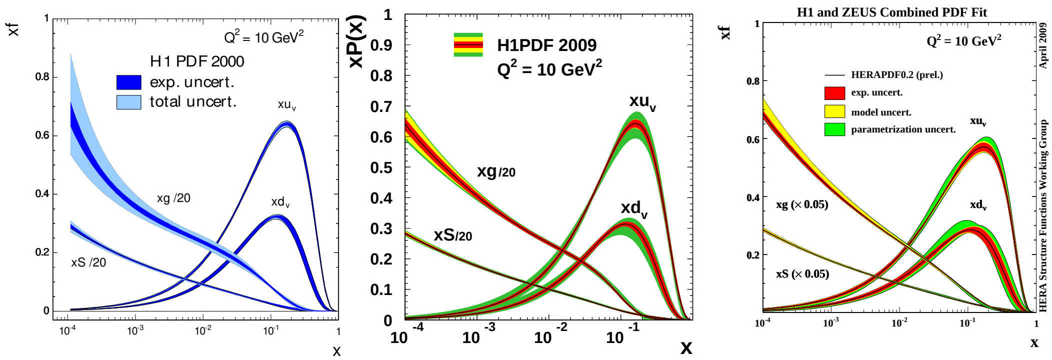

Figure 4: PDFs of the previous and current QCD fits by the H1 collaboration (left and middle) and the preliminary combined H1 and ZEUS fit (right) at $Q^2 = 10\,\mathrm{GeV}^2$. Gluon and sea quark distributions are scaled down by a factor of 20. The bands denote the experimental, model, and parametrisation uncertainties from inner to outer band.

5 Conclusions

A new measurement of the inclusive DIS cross section for $12\,\mathrm{GeV}^2 \leq Q^2 \leq 150\,\mathrm{GeV}^2$ is performed using H1 data from the year 2000. The new measurement is combined with the published 1996/97 data, after correction of a small bias in the older result. The result is the most accurate measurement in this kinematic domain to date with typical total uncertainties of $1.3-2\%$. A QCD analysis, H1PDF 2009, is performed using improved new data at $Q^2 \leq 150\,\mathrm{GeV}^2$ and published H1 high Q^2 inclusive cross section measurements. The fit is able to describe all the data very well and supersedes the previous H1 fit.

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